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Multi-Criteria Selection of the Preferred Protocol of Routing in Ad-Hoc Networks by Hierarchies Analysis Method

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Abstract: ***Wireless ad-hoc networks are mobile decentralized dynamic self-organizing networks that do not have a fixed structure. This technology of building a wireless network is relevant in situations where you need to quickly deploy a network in a territory with mobile nodes. This article discusses the features of applying the hierarchy analysis method for multi-criteria selection of the preferred routing protocol in ad-hoc networks from a number of options.***

Keywords: routing protocol, ad-hoc networks, hierarchy analysis method

1. Introduction

Wireless ad-hoc networks belong to mobile decentralized dynamic self-organizing networks that do not have a permanent structure [1-5]. Each device participating in the organization of such a network can be a transmitter, receiver, relay, and end device. Each ad-hoc network node can freely move at any time and in any direction, and as a result of this, some old connections may be lost, and new connections can already be established with other network nodes. This technology of building a wireless network is relevant in situations where you need to quickly deploy a network in a territory with mobile nodes. Examples of such situations are natural disasters, military operations and other emergency situations. Due to the constant change in the network structure, routing problems can occur, since possible ways of delivering information between nodes change.

An analysis of the literature [1-5] showed that these problems are solved using proactive, reactive, and hybrid routing protocols. It should be noted that each routing protocol is characterized by a set of quality indicators that determine the main properties of the selected routing method. The quality indicators of routing protocols are usually interconnected and are antagonistic when other quality indicators deteriorate when one quality indicator improves.

When building ad-hoc networks, there is a need to choose the preferred routing protocol, taking into account a set of conflicting quality indicators. In these cases, for a comparative analysis and selection of a preferred routing protocol, multicriteria optimization methods should be applied [6]. There are different methods of multi-criteria selection. Therefore, the justification of the method of choosing the best options for systems, taking into account the totality of quality indicators is an urgent task.

This article discusses the features of applying the hierarchy analysis method [7] for the multi-criteria selection of the preferred routing protocol in ad-hoc networks from a number of options.

2. Analysis of the Original Set of Routing Protocols in Ad-Hoc Networks

Proactive DSDV, OLSR, WRP protocols, as well as reactive protocols AODV, DSR [1-5] are the most commonly used in ad-hoc networks. Let us consider briefly some of the features of these routing protocols.

DSDV (Dynamic Source Routing protocol) is a protocol based on the Bellman-Ford algorithm that sends updates immediately after receiving them. Each update of the routes of each node has its own unique sequence number, which allows to ensure the relevance of information about routes. It provides the ability to connect one of the nodes of the ad-hoc network to any other network, in which case this node is a gateway.

OLSR (Optimized Link State Routing Protocol) is a protocol based on the Dijkstra algorithm. It introduced the concept of network devices that play the role of the MPR (Multi Point Relay) and, in fact, are the basis of the ad-hoc network. It is the MPR devices that can generate and send updates across the entire ad-hoc network. Each device that does not play the role of the MPR selects one or more such MPR devices from which it receives updates of the routing information, but does not translate it into the network.

WRP (Wireless Routing Protocol) is a protocol based on the periodic exchange of routing tables and basic protection means against occurrence of routing loops. It creates connections that are constantly maintained between adjacent nodes of the ad-hoc network.

AODV (Adhoc On-Demand Distance Vector) is a protocol that uses a distance vector on demand. It allows the customer to establish a connection with another customer, if necessary, by distributing the request over the entire ad-hoc network. All nodes that have received the request store the sender information in the routing table and the response to the request returns along the established route.

DSR (Dynamic Source Routing protocol) is a protocol that is similar to AODV, but does not use the source routing. Here, the path of the packet through all nodes is indicated inside the packet and the response packet is returned along the same route as the request arrived.

3. Mathematical Features of the Hierarchy Analysis Method

The choice of the preferred routing protocol in ad-hoc networks will be carried out by the method of hierarchy analysis (MAI) [7].

The essence of this method consists in decomposing the problem of choosing a single preferred variant of the projected system from a certain set of variants taking into account a set of quality indicators. The principle of decomposition involves structuring of the problem of choice in the form of a hierarchy of levels from the top (the goal of choice) through the intermediate level 2 (system quality indicators) to the lowest level 3 (alternative variants for building a system). Then the subjective judgments are received from the experienced experts in the form of pairwise comparisons of the relative importance of various elements of the problem of choice. Matrices of paired comparisons of the elements of the choice problem are compiled as a result of the obtained numerical data processing. The main eigenvectors corresponding to the maximum eigenvalues are calculated for these matrices. Further, according to certain mathematical procedures, a vector of global priorities is obtained, the components of which determine the priority of choosing the preferred variant of the designed system. The maximum value of the components of the global priorities vector corresponds to the only preferred variant of the system out of a given set of variants.

The principle of comparative judgments of experts in the HAM is that the elements of the problem of choice are compared by experts in pairs in importance. The relative importance of different system variants (at level 3) and different system quality indicators (at level 2) are compared in pairs. The results of pairwise comparisons are reduced to the matrix form

$$A = \begin{pmatrix} a_{11}a_{12}...a_{1j} \\ a_{21}a_{22}...a_{2j} \\ ... \\ a_{i1}a_{i2}...a_{ij} \end{pmatrix}, \qquad (1)$$

where $a_{ij} = \frac{w_з}{w_j}$ – are the estimates of pairwise comparisons of various elements of $w_з, w_j$ choice.

The diagonal of this matrix is filled with the values "1", and the matrix elements below the diagonal are filled with the corresponding inverse values.

Estimates of pairwise comparisons of elements a_{ij} are found using subjective judgments of experts, numerically determined on a scale of the relative importance of elements, which is presented in Table 1.

Table 1: The scale of the relative importance of the comparison elements

Relative importance	Definition
1	Equal importance of comparison elements
3	Moderate superiority of one element over another
5	Substantial superiority of one element over another
7	Significant superiority of one element over another
9	Very strong superiority of one element over another
2,4,6,8	Intermediate decisions between two judgments

Next, the processing of the generated matrix of pairwise comparisons is performed, which, from a mathematical point of view, is reduced to the calculation of the main eigenvector corresponding to the maximum eigenvalue of the matrix. The components of the main eigenvector of the matrix of pairwise comparisons of quality indicators are calculated as the geometric average value in the row of the matrix of pairwise comparisons.

$$V_j = \sqrt[n]{\prod_{i=1}^{n} a_{ij}}, \quad j = \overline{1, n}, \qquad (2)$$

where n – is the number of quality indicators.
The components of the main eigenvector are used to calculate the corresponding components of the priority vector in the form of normalized values

$$P_j = \frac{V_j}{S}, \quad j = \overline{1, n}, \qquad (3)$$

where $S = \sum_{j=1}^{n} V_j$.
Such procedures are performed initially at level 2 for system quality indicators. Similarly, there are found the estimates of matrices of pairwise comparisons of options for systems at level 3 separately with respect to each system quality indicator. On the basis of these matrices, according to (2) and (3), the components of the corresponding main eigenvectors and system priority vectors are calculated with respect to the individual indicators of the quality of the system $\vec{Q}_j$, $j = \overline{1, n}$.

Using the obtained priority vectors, the values of the global priorities $\vec{C}$ vector components are calculated according to the relation

$$C_i = \sum_{j=1}^{n} P_j Q_{ij}, \quad i=\overline{1,N}, \qquad (4)$$

where N - is the number of compared variants of the systems.

The resulting vector of global priorities is used when choosing the preferred variant of the system. According to the HAM, the maximum value of one of global priorities vector components corresponds to the preferred variant of the system (4).

4. Justification of the preferred version of the HAM-based Routing Protocol

Let us consider the features of application of the method for analyzing hierarchies to select the only preferred variant for the routing protocol in ad-hoc networks, taking into account a set of quality indicators. Quality indicators, in particular, convergence time, memory, and control were chosen as the main characteristics of the protocolsю

Table 2 shows the relationships [5] that determine the dependence of quality indicators on the main characteristics of the network, in particular, O () means the order of complexity; D is the diameter of that these quality indicators are interconnected and competing in nature.

Table 2: Quality indicators of routing protocols

Type of the routing protocol	Protocol quality indicators		
	Convergence time	Memory	Control
DSDV	O(D·I)	O(N)	O(N)
OLSR	O(D·I)	$O(N^2)$	$O(N^2)$
WRP	O(h)	$O(N^2)$	O(N)
AODV	O(2·D)	O(2·N)	O(2·N)
DSR	O(2·D)	O(2·N)	O(2·N)

Fig. 1 shows a hierarchical representation of the problem of choosing a preferred routing protocol. There is the goal of choosing the preferred protocol variant at level 1, the quality indicators of the protocols are at level 2, and alternative protocol options are at the third level.

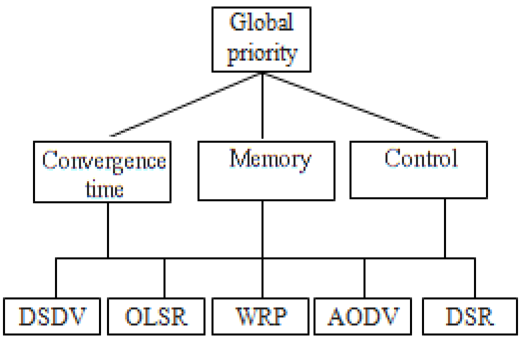

Figure 1: Decomposition of the problem of choice

According to the HAM, a matrix of pairwise comparisons was constructed for a set of quality indicators (i.e., level 2) (Table 3). To fill this table with the help of an experienced expert, a pairwise comparison was made of the importance of the selected quality indicators that determine the complexity of the routing protocols, in particular, convergence time, memory, and control. The diagonal of this matrix is filled with the values "1", and the matrix elements lying below the diagonal are filled with inverse values.

Table 3: Matrix of pairwise comparisons of the quality of the routing protocols and the calculated estimates of the priorities vector components

	Convergence time	Memory	Control	Eigen vector V_i	Priority vector Q_{ij}
Convergence time	1	1/3	1/5	0,405	0,1006
Memory	3	1	1/4	0,909	0,226
Control	5	4	1	2,71	0,673

Next, pairwise comparisons at level 3 are performed in the form of the relative complexity of alternative variants of protocols with respect to each quality indicator. As a result of processing the obtained matrices, the eigenvectors and priorities vectors are calculated according to (2) and (3), which are listed in Table 4, 5, 6.

Table 4: Matrix of pairwise comparisons of routing protocols with respect to convergence time

	DSDV	OLSR	WRP	AODV	DSR	Components of eigenvector V_{i1}	Priority vector components Q_{i1}
DSDV	1	1/2	4	5	5	2,186	0,323
OLSR	2	1	4	5	5	2,885	0,427
WRP	¼	¼	1	1/3	1/3	0,368	0,054
AODV	1/5	1/5	3	1	2	0,752	0,111
DSR	1/5	1/5	3	1/2	1	0,569	0,084

Table 5: Matrix of pairwise comparisons of routing protocols with respect to the memory

	DSDV	OLSR	WRP	AODV	DSR	Components of eigenvector V_{i2}	Priority vector components Q_{i2}
DSDV	1	1/4	1/4	1/3	1/3	0,368	0,06
OLSR	4	1	2	3	3	2,352	0,384
WRP	4	½	1	3	3	1,782	0,291
AODV	3	1/3	1/3	1	2	0,918	0,15
DSR	3	1/3	1/3	1/2	1	0,698	0,114

Table 6: Matrix of pairwise comparisons of routing protocols with respect to control

	DSDV	OLSR	WRP	AODV	DSR	Components of eigen vector V_{i3}	Priority vector components Q_{i3}
DSDV	1	1/5	1/2	1/3	1/3	0,026	0,004
OLSR	5	1	5	3	3	2,954	0,459
WRP	2	1/5	1	1/3	1/3	0,534	0,083
AODV	3	1/3	3	1	2	1,428	0,222
DSR	3	1/3	3	1/2	1	1,485	0,231

Table 7 summarizes the obtained estimates of the components of quality indicators priorities vector as well as the priorities vectors of the routing protocols, in relation to the time of convergence, memory, control. Using these priority vectors, the values of the global priority vector components are calculated according to (4), which are listed in the last column of Table 7.

Table 7: Results of calculating the values of the global priority vector components

No.	Type of the routing protocol	Q_{ij}			C_i
		$j=1$	$j=2$	$j=3$	
1	DSDV	0,323	0,06	0,004	0,048
2	**OLSR**	**0,427**	**0,384**	**0,459**	**0,438**
3	WRP	0,054	0,291	0,083	0,127
4	AODV	0,111	0,15	0,222	0,194
5	DSR	0,084	0,114	0,231	0,189
P_j		0,1006	0,226	0,673	

The preferred version of the routing protocol in ad-hoc networks taking into account the entered quality indicators is chosen by the maximum value of the components of the global priorities $\tilde{N}_i$ vector. This is the OLSR routing protocol based on the Dijkstra algorithm.

5. Conclusions

1) The characteristics of different routing protocols in wireless ad-hoc networks taking into account a set of quality indicators are analyzed.
2) The mathematical features of one of the methods for multi-criteria selection of the preferred variant, the hierarchy analysis method, are considered.
3) Matrices of pairwise comparisons of quality indicators and variants of routing protocols are obtained, for which their main eigenvectors and priority vectors are calculated.
4) Based on the data obtained, the global priorities vector was received, the preferred routing variant in a wireless ad-hoc network was chosen by the maximum value of this vector components.

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